

Military medical revolution: Military trauma system

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The development and advancement of trauma care has shown stepwise improvements for centuries owing to the interrelationship of civilian and military medical systems. With respect to trauma systems, the sophisticated civilian trauma system in the United States was born directly out of the successes and lessons learned from the Vietnam War. The American College of Surgeons (ACS) took the lead in advocacy for US trauma systems and, in 1972, published *Early Care of the Injured Patient*¹ followed in 1976 by the first iteration of the *Optimal Resources for Care of the Injured Patient*.² These documents outlined resources and practices to optimally care for injured patients across the continuum of care within the civilian spectrum. Numerous subsequent studies and analyses demonstrated that inclusive trauma centers and trauma assistance systems improve trauma outcomes.

The development of combat casualty care capabilities during the current contingency operations has been a revolutionary story of successful adaptation and evolution, which has driven substantive improvements in the care of the battlefield casualty. This revolution was initiated in 2004 with the inception of a formal military trauma system, the Joint Trauma System (JTS). The purpose of the JTS was to develop a novel systematic and integrated approach to organize and coordinate combat casualty care. The basic principles of the trauma system were founded on four simple tenets: right patient, right place, right time, right care with the guiding vision that every soldier, sailor, airman, and marine injured in the battlefield will have the optimal chances of survival and functional recovery.³ In 2005, the JTS was originated within the US Army Institute of Surgical Research (USAISR) to support the overarching architecture of the entire continuum of combat casualty care from point of injury through rehabilitation. To support the development of this new military trauma system, a Joint Theater Trauma Registry

(JTTR) was developed concurrently and became functional in early 2005. The JTTR captured injury demographics, anatomic and physiologic parameters, and trauma care and outcomes across the continuum of combat casualty care. This registry data provided vital information used to effect improvements in clinical care, drive medically related doctrine and policy, and support the creation of new knowledge through research. The revolutions in military medical affairs (RMMA) relative to the military trauma system are shown in Table 1.

Joint Trauma System

Clinical Performance Improvement

Battlefield injury care clinical performance improvements were driven by two major pathways: evidence-based practice guidelines and telemedicine. The goal of clinical practice guidelines (CPGs) is to serve as a resource for military providers to reduce practice variation. The value of battlefield medicine CPGs has been demonstrated in numerous series. Representative impact of CPGs has been manifested in several analyses to include burn resuscitation-associated abdominal compartment syndrome mortality in which mortality decreased from 36% to 18% after introduction of the CPG. Similarly, hypothermia on presentation decreased from 7% to 1% after introduction of the CPG. Perhaps, most notably, mortality in those receiving massive transfusions has been dramatically reduced from 32% to 20% after introduction of the damage-control resuscitation (DCR) paradigm and its associated CPG.^{4,5}

As technology and communication access improved, a performance improvement tool using telemedicine conferencing was developed. This conferencing capability allowed providers across the continuum of care to discuss active patients as they were evacuated. The value of this program was twofold: it allowed providers at receiving facilities to understand the management subtleties and rationale for patients at previous facilities and gave providers valuable opportunities for feedback and loop closure of performance improvement issues through near-real-time interaction.

Medical Decision Making

Medical decision making in the battlefield is most useful when supported by strong data. Using the JTTR data, the trauma system published a monthly theater trauma surveillance report. This tool, along with other products of the JTS, provided valuable information to military leadership for use in injury prevention, resource allocation, and management and supporting advanced capabilities in the battlefield.

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TABLE 1. RMMAs, 2001 to 2011 Overseas Contingency Operations in Afghanistan and Iraq

Overseas Contingency Operation	RMAA
Trauma system	JTTS
	Theater CPGs
	CoTCCC
	PHTR
	ACS Trauma Center Verification for LRMC
	Combat Theater-Based HRP
	SVS Program
National hospital care and rehabilitation	Complex Battle Injury Task Force
	Prosthetics and orthotics
	Regenerative medicine, AFIRM

Development of New Knowledge

Although not specifically developed as a research tool, combat casualty care data from the JTTR have been used extensively through the formal institutional review board process to augment the knowledge base of injury care cited by more than 200 peer-reviewed articles in the scientific literature. JTS initiatives have revolutionized field trauma care as demonstrated by improved survival and functional outcomes after battlefield injury. The JTS has set the standard for trauma care on the modern battlefield using contemporary systems-based methodologies and will continue to foster advances in military medicine.

Committee on Tactical Combat Casualty Care

In the mid-1990s, medics, corpsman, and pararescuemen in the US military were taught to manage trauma in the battlefield using training curricula that were based on the approach used in civilian trauma courses. These courses emphasized civilian principles of care such as the “ABC approach,” starting two large-bore intravenous lines on every significantly injured patient, large-volume crystalloid fluid resuscitation for casualties in shock, and an avoidance of tourniquet use for fear of causing ischemic damage to extremities.⁶ Reports of preventable deaths in combat casualties in previous conflicts^{7,8} highlighted the opportunity to reduce preventable death in combat casualties through a focus on improved battlefield trauma care. In the mid-1990s, a medical research effort funded by the US Special Operations Command (USSOCOM) and performed in partnership with the Uniformed Services University of the Health Sciences conducted a comprehensive review of battlefield trauma care as practiced in the US military, with particular focus on first-responder care.

The final product was a new concept called *tactical combat casualty care* (TCCC); TCCC is essentially a set of battlefield trauma care guidelines that have been customized for use by combat medics in the battlefield.⁶ The core principles of TCCC are to avoid preventable deaths and to combine good medicine with good tactics.

Many of the concepts noted in the 1996 *Military Medicine* TCCC article were not new but rather were built on observations and recommendations of earlier authors;^{7–11} these recommendations had, however, never been woven into a comprehensive set of battlefield trauma care strategies such

as TCCC. Lacking this structure, they were transitioned into combat trauma care courses in the military only sporadically, if at all. Of note, many elements of prehospital trauma care that were widely accepted as gospel were found to be not well supported by the available evidence. Not surprisingly, preventable death analyses from early in the Iraq and Afghanistan conflicts found that a significant incidence of potentially preventable death was still present in US combat fatalities.^{12,13} TCCC proposed many fundamental changes to trauma care for the combat environment.

The Committee on Tactical Combat Casualty Care

To provide a methodology for updating TCCC as new evidence in battlefield trauma care becomes available, USSOCOM sponsored the establishment of the Committee on Tactical Combat Casualty Care (CoTCCC) in 2001. The CoTCCC was located first at the Naval Operational Medicine Institute and later moved to the Defense Health Board (DHB). The CoTCCC is a triservice and civilian group that includes trauma surgeons, emergency medicine physicians, combatant unit physicians, and combat medical personnel. Meetings are held quarterly, and recommendations for changes to the TCCC Guidelines are made as needed. TCCC publishes its recommendations online and in the *Prehospital Trauma Life Support Manual*, which is endorsed by the ACS Committee on Trauma (ACS-COT) and the National Association of Emergency Medical Technicians. The TCCC guidelines are the only comprehensive set of trauma guidelines customized for use in the battlefield that has won this dual endorsement. In this recent decade of conflict, the CoTCCC has learned how to gather and analyze new information relating to battlefield trauma care and to translate that information into action.^{14,15}

TCCC in 2012

With the leadership of the CoTCCC, the TCCC guidelines have incorporated the lessons learned from the current conflicts and new trauma literature and now include features such as the following: phased care designed to combine good medicine with good tactics; aggressive tourniquet use to control life-threatening extremity hemorrhage; Combat Gauze to control external, nonextremity hemorrhage; the Combat Ready Clamp for junctional hemorrhage; tranexamic acid for noncompressible hemorrhage; aggressive use of surgical airways in casualties with airway trauma; prompt needle decompression of suspected tension pneumothorax; modified spinal precautions for casualties with penetrating trauma; limited use of intravenous access for combat casualties; hypotensive resuscitation with Hextend for casualties in shock; intraosseous infusion techniques when vascular access is needed but difficult to obtain; better battlefield analgesia with intravenously administered morphine and oral transmucosal fentanyl citrate; an emphasis on the prevention of coagulopathy in combat casualties; battlefield antibiotics to avoid preventable deaths from wound infections, especially in situations where evacuation is delayed; scenario-based combat trauma training; and an increased use of plasma early on in trauma resuscitations (Dickey et al. DHB memo dated June 14, 2011, and DHB memo dated September 23, 2011).^{16–24} TCCC training has been recommended by the DHB for all

deploying combatant personnel and for the medical providers who support them (DHB memo, TCCC training).

TCCC—Saving Lives in the Battlefield

TCCC has been noted in multiple published reports to have been successful in saving lives in the battlefield.^{25–32} After a decade of war, TCCC has emerged as the standard of care for managing trauma in the battlefield. It is used throughout the US military¹⁷ and by coalition partner nations³³ (also SP Amor letter dated February 22, 2011). TCCC represents a revolutionary change in the training of combat medics in all three services.

Prehospital Trauma Registry

The considerable potential for prehospital care to increase the salvage of combat casualties through those listed as killed in action is not a novel concept.⁸ Likewise, it has been known that civilian trauma victims have the potential to benefit in similar fashion.³⁴ Although TCCC offered a paradigm shift in prehospital trauma care, with the potential to substantially increase combat casualty survivability, validation of TCCC protocols and procedures ultimately requires data collection and analysis. Collection of prehospital data in the battlefield has proven to be a challenge.³⁵ Although documentation of prehospital care can be beneficial to individual patients, this tenet alone has failed to consistently motivate prehospital personnel to document care. The Field Medical Card (DD Form 1380) is another barrier because it is not TCCC-based and is medic centric instead of casualty centric. In 1999, the 75th Ranger Regiment developed a Ranger Casualty Card to document prehospital trauma care that was consistent with TCCC guidelines. In addition, because all personnel have the potential to become a casualty or to be a prehospital first responder, all personnel carried this casualty card. The use of this casualty card quickly spread throughout the USSOCOM and multiple other combatant units in both Afghanistan and Iraq. This card was modified slightly and adopted as the official TCCC Casualty Card in 2009 by the US Army.

With the start of the conflict in Afghanistan in 2001, the 75th Ranger Regiment initiated a rudimentary prehospital database from data captured through after-action reports and a Ranger Casualty Card collection program, which has been expanded into a Web-based Prehospital Trauma Registry (PHTR) software tool to capture Ranger Casualty Card data. This registry includes basic statistical analysis and instant data graphing functions, providing combatant unit commanders and prehospital medical personnel with near-real-time trends and reports for lessons learned, quality assurance, and rapid implementation of protocols and initiatives designed to immediately reduce morbidity and mortality in the battlefield.^{20,36–40} Thus, this registry afforded combatant unit personnel with the ability to quickly and autonomously make evidence-based decisions based on objective data. The immediate feedback provided by the PHTR helped to motivate and propagate data collection at the combatant unit level.

The PHTR developed by the 75th Ranger Regiment is a novel effort within the US military. Not only does a PHTR

keep combatant unit leaders engaged and informed on the health and welfare of their personnel, but it also augments leaders' decision-making processes. The PHTR prompts performance improvements in prehospital casualty care, generates novel treatment strategies, and further refines personnel, training, and equipment initiatives. A detailed PHTR validates force protection requirements and directs procurement in a cost-effective manner. Commanders and medical providers gain invaluable knowledge on tactics, techniques, and procedures that result in lives saved in the battlefield. Combatant unit commanders with appropriately trained prehospital personnel do have the potential to eliminate preventable death in the battlefield.⁴⁰ A PHTR can validate and refine the training of prehospital personnel to accommodate this goal.

ACS Trauma Center Verification

Landstuhl Regional Medical Center (LRMC) is a permanent US military installation and is the largest American military hospital outside the United States. It is staffed by military personnel from the three services as well as US and host-nation civilians. Since 2003, LRMC has provided care to nearly all ill and injured casualties evacuated out of the combat theaters of Iraq and Afghanistan.

In 2006, a process began at LRMC to meet ACS Level II criteria and obtain Level II verification to demonstrate that the resources, staffing, educational programs, and expertise available at LRMC were comparable with a civilian trauma centers in the United States.⁴¹ The ACS Level II review team found no criterion deficiencies, few weaknesses, and a multitude of trauma care strengths, which led to verification. The committee recommended that LRMC submit a future application to seek Level I verification because of the outstanding care that it delivered and the trauma performance improvement systems it had in place.

During the next 3 years, the LRMC trauma staff continued to receive casualties from the war and to improve their clinical outcomes. They expanded their trauma research program and postgraduate residency training positions. In 2010, LRMC leaders, with the concurrence of the Surgeon General of the US Army, submitted an application for Level I verification with a site inspection in May 2011. The ACSCOT review team reported no criterion deficiencies. In July 2011, LRMC was verified as one of 142 US hospitals with ACS Level I Trauma Center designation. LRMC remains the only verified center outside the United States. The approval solidified additional resources and staff to efficiently and expertly manage the flow of traumatically injured military personnel who arrived at LRMC daily.

Senior Visiting Surgeon Program

The Senior Visiting Surgeon (SVS) Program is a profound change for military trauma care. It was the first program in which military and civilian surgeons worked side by side at one location, learning from each other and synergistically caring for the combat wounded. In 2006, the American Association for the Surgery of Trauma and the ACSCOT developed a civilian SVS program with LRMC hospital and military trauma leaders.⁴² During this period, LRMC was completing its transition from

a prewar community-based hospital to its current role as a key trauma evacuation center in the JTS care continuum. The program's objectives were to (1) benefit casualty care by bringing years of civilian trauma care experience to the bedside, (2) develop trauma center and system practices, (3) mentor military physicians, and (4) facilitate scientific exchange between military physicians and civilian trauma leaders, potentially leading to advances in trauma care through cooperative research projects. Civilian trauma experts travel to the LRMC for 2 weeks to 4 weeks and conduct patient rounds, perform surgical procedures, provide educational lectures for continuing medical education, serve as scientific mentors, and advise on performance improvement activities.⁴³ Over time, as the LRMC trauma experience grew, the program became a means to transfer military lessons learned from the battlefield back to civilian wound care management, DCR, and hemorrhage control.⁴⁴ The success of the SVS has spawned similar programs in orthopedics, vascular surgery, and neurosurgery.⁴⁵

Combat Theater-Based Human Research Protection Program

As had occurred in earlier wars, medical personnel supporting the sustained military operations in Iraq and Afghanistan recognized the need to systematically analyze clinical data being generated as care was delivered in support of combat operations.^{43,44} However, unlike in earlier conflicts, research conducted in the contemporary theater of combat operations was subject to meeting modern statutory and regulatory requirements for conducting human subjects research designed to ensure that subjects' safety, rights, welfare, and privacy were protected. The development of a fully compliant military medical research enterprise in an active combat theater represents a revolution in military medical affairs.

As operations in Iraq became sustained in 2003 to 2004, there was vocal demand for a Multinational Corps–Iraq (MNC-I) human research protection program (HRPP) that would permit combat casualty care research in theater. This was to be the first Combatant Command HRPP. The key elements MNC-I HRPP included the designation of the MNC-I surgeon as the institutional signatory of the Department of Defense Assurance, the requirement for MNC-I surgeon approval, scientific review of research involving human subjects by the USAISR scientific review committee and review and approval by the institutional review board at San Antonio Military Medical Center. MNC-I HRPP was the commitment to ensure that investigators were trained in the tenets of human subjects' protections. Since the development of the initial MNC-I HRPP and approval of the first implementation of a Combatant Command Department of Defense Assurance in 2005, the program has matured, and currently, a broader CENTCOM HRPP covering research conducted in Iraq, Kuwait, and Afghanistan was developed, and an Army-approved Central Command Assurance was signed in August 2009. The creation of the first ever combatant command-based HRPP permitted the conducting of approximately 250 combat human research protocols since 2005 and, most importantly, assured the protection of the safety, rights, and welfare of the participants in those studies. This system and the research it supports have proven to be a lynchpin of numerous

improvements to combat casualty care as well as a crucial element in ensuring that these innovations reach civilian trauma care.

Task Force Battle Injury Evaluation

In July 2011, the official report of the US Army Surgeon General's Joint Task Force on Dismounted Complex Blast Injuries was released to senior leadership, and subsequently a nonclassified version was released to the public. The formation, organization, and findings of this task force represent exemplary interservice and interdisciplinary cooperation made possible through the JTS. During the course of 2010, data from the JTTR served to identify a change in trends for battle casualties evacuated from Afghanistan. Specifically, surgeons noted an increase in the frequency of multiple limb amputations and association with genitourinary injuries. The trend continued to rise through October 2010, which typically had been a shift point into less intense winter action. In fact, surgeons at LRMC noted that the monthly total of amputations in October 2010 was higher than any total for an entire year for this conflict.

In December 2010, the Army Surgeon General commissioned a task force to study these injury patterns. He charged the task force to characterize and describe the trends, determine whether this trend represented a new injury pattern and whether this trend was related to tactical trends that the medical community could identify, and describe areas for improvement in medical treatment and rehabilitation to influence ultimate outcome for these individuals. Subject experts were identified and invited to participate in five focus areas as follows: point of injury/immediate care, acute resuscitative care at Role 2 or 3 facilities, aeromedical evacuation, definitive surgical care/reconstruction and rehabilitation, and operational considerations within the scope of the medical community that would facilitate enhancement of treatment outcomes. Because of the operational nature of this task force, members included the USSO-COM, Forces Command, the CoTCCC, and the Joint IED Defeat Organization in partnership with Joint Trauma Analysis and Prevention of Injury in Combat teams.

The initial main effort provided a consensus on definition of the injury pattern: traumatic amputation of at least one leg; a minimum of severe injury to another extremity; and pelvic, abdominal, or urogenital wounding. Focus subgroups then divided and met independently during a period of 8 weeks to determine gaps and best practices for improvement and overlap between subgroups.

The report, with 74 recommendations, identified the success of existing data collection systems and the contributions of lifesaving measures from point of injury to DCR. It emphasized the success of the CoTCCC and supported previously presented recommendations as well as potential benefits of training specific management of the injury pattern for care providers from combat medics to flight paramedics to urologic surgeons with reconstructive expertise in the Role 3 deployed facilities as well as long-term rehabilitation experts in both Department of Defense and Veterans Affairs systems. Improvements in hemorrhage control and enhancement of initial resuscitation as well as materiel acquisitions for hemorrhage control and explosion detection or mitigation were identified. The report supported the increase in resource allocation for definitive surgical reconstruction and intensive long-term rehabilitation

as well as an overall holistic human-centered approach to care, to include initial pain management and predeployment family planning. For a full review, please refer to the Task Force Report.^{46,47}

In summary, the identification of increases in injury and collection of expertise to characterize, analyze, and make recommendations for prevention, best management, and mitigation took place in less than 9 months and included development of a campaign plan for implementation as a result of data tracking and theater-wide communication. This communication revolution constitutes a major landmark after a decade at war.

National Hospital Care and Rehabilitation

Prosthetics and Orthotics

Great advances have been made in prostheses, benefiting the more than 1,400 soldiers who have sustained a major limb amputation. Silicone liners allow better fitting and use in even skin-grafted residual limbs. Energy-storing prostheses (Fig. 1) allow for higher-intensity activity, whereas motorized prostheses allow for more normal walking gaits, particularly downstairs or downhill. Myoelectric hands have not substantially changed in the past few decades, but integrated neural components and improved responsiveness and speed hold the promise of allowing upper-limb amputees to use their hands for more intricate movements while providing a more natural look and feel.

In 2009, an energy-storing orthotic (Fig. 2) was developed at the Center For the Intrepid, Fort Sam Houston, Texas. This custom-fit orthotic offloads the weight to the leg and relieves pain, improving functional performance.^{48,49} The advances in prosthetics and orthotics, improved pain control, and aggressive rehabilitation have allowed a return-to-duty rate of approximately 20% for soldiers who have had a lower-limb amputation⁵⁰ and limb salvage as well.⁵¹

Three multidisciplinary, state-of-the-art advanced rehabilitation centers—at Fort Sam Houston, Texas (Fig. 3); in Washington, DC; and in San Diego, California—have been constructed to improve outcomes of amputations, functional limb loss, and burns in collaboration with seven Veterans Administration Regional Amputation Centers. Patients receive state-of-the-art physical therapy and occupational therapy, including demanding and challenging sports equipment and virtual reality systems. The centers also offer individualized



Figure 1. Energy-storing prosthetic.



Figure 2. Energy-storing orthotic (IDEO, US Army photo by Steven Galvan, US Army Institute of Surgical Research Public Affairs Officer).

case management, access to behavioral medicine services, and in-house prosthetic fitting and fabrication. This approach goes beyond normal rehabilitation by striving for reintegration of wounded soldiers back into military service or society.

Regenerative Medicine

Regenerative medicine—with the goal of replacing current practice of reconstruction of combat wounds resulting in tissue loss with restorative technologies—must be considered a nascent RMMA at present. The Armed Forces Institute of Regenerative Medicine (AFIRM) is a multi-institutional, interdisciplinary network working to develop advanced treatment options for severely wounded service members (<http://www.afirm.mil>). AFIRM consists of more than 200 scientists from all over the United States, working as partners with the USAISR. AFIRM is managed and funded through the US Army Medical Research and Materiel Command (MRMC),⁵² with additional funds from the US Navy (Office of Naval Research), the US Air Force (Office of the Surgeon General), the National Institutes of Health, the Veterans Administration, the Department of Defense (Health Affairs), and local public and private matching fund programs. Leveraged at more than 300 million dollars, AFIRM has a 5-year grant to develop regenerative medicine technologies and products with emphasis on burn repair (skin



Figure 3. Center for the Intrepid (photograph from the Brooke Army Medical Center Web site).

substitute), limb and digit salvage (bone, muscle), craniofacial reconstruction, face and hand allotransplantation, and scarless wound healing. AFIRM's governance, oversight committee structure, and competitive involvement of scientists is in itself a revolutionary process that promises to produce a revolutionary advancement of technologies to restore missing and damaged anatomy to full form and function in the near future. Eleven clinical trials are already under way.⁵³

CONCLUSION

One of the principal medical legacies of the current conflict will be the development and implementation of a formal battlefield trauma system. To mimic civilian trauma system outcome successes with the inception of current contingency operations, the Joint Theater Trauma System (JTTS) was developed as a systematic and integrated approach to better organize and coordinate battlefield care to minimize morbidity and mortality and optimize the ability to provide essential care required for casualty injuries. The JTTS was promulgated with the vision that every soldier, marine, sailor, or airman injured in the battlefield or in the theater of operations will be provided with the optimal chance for survival and maximal potential for functional recovery. The purview of the JTTS system includes injury prevention, prehospital care, acute hospital care, rehabilitation, education, leadership and communication, quality improvement/performance improvement, research, and associated information systems. Trauma system successes have dramatically improved combat casualty care outcomes.

AUTHORSHIP

L.H.B. was responsible for the concept and design of this article, compilation of the text, figure and table composition, and extensive reviews. All authors listed contributed a section, with references, in their area of expertise and reviewed the article. In addition, D.G.B. and B.J.E. provided extensive reviews of the article.

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